Design of Waller Beach Outlet Facility for Waller Creek Stormwater Project, Austin, Texas, USA

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ABSTRACT

This paper provides an overview of the $15 million shaft and associated hydraulic structures designed to be constructed within the Waller Creek Stormwater Tunnel Program, a tunnel in downtown Austin, Texas, that helps prevent severe flooding and stream bank erosion by controlling the volume of water in the creek. The features of the project, including the shaft, spillway, lagoon, and associated river works required for the discharge of the submerged siphon into Lady Bird Lake are described. The shaft is sunk within a cofferdam in the lake through overburden, Austin Limestone, and the Eagleford Shale. This paper explains the engineering rationale and identifies the geotechnical conditions and environmental constraints that dictated the design features and the likely required construction methodology.

INTRODUCTION

The purpose of this paper is to explain the engineering rationale, geotechnical conditions, and environmental constraints that dictated the design features and construction methodology for the Waller Creek Tunnel Outlet Facilities at Waller Beach in Austin, Texas.

The following brief description of the overall project explains the context of the outlet facilities. The Waller Creek Tunnel Project provides 100-year flood protection to the Waller Creek watershed through a stormwater bypass tunnel, captures and redirects flood waters south of 12th street and safely carries them to Lady Bird Lake. The majority of the Waller Creek District in downtown Austin lies within a 100-year flood plain and has been subject to severe flooding and erosion.

The project begins in Waterloo Park where an inlet structure takes in flood waters and screens out trash and debris. Two additional inlets capture flood waters along the length of the tunnel. The tunnel prevents severe flooding and stream bank erosion by controlling the volume of water in the creek. The tunnel empties the diverted waters into a lagoon on the shores on the Lady Bird Lake, providing water quality and erosion control benefits via a 5,700 lf, 20.5-ft to 26.5-ft diameter equivalent tunnel.

This flood control tunnel is located in a geologic formation that includes Austin (Buda) Limestone, Eagle Ford Shale, and alluvium. The study phase included extensive hydrologic and hydraulic modeling and design for the inlet and outlet structures. The inlet structure design includes a 27-cfs recirculation pump station to maintain dry weather water quality in the tunnel and in Waller Creek. Flood water and recirculation water screening systems were also designed. The outlet structure location is shown in Figure 1.

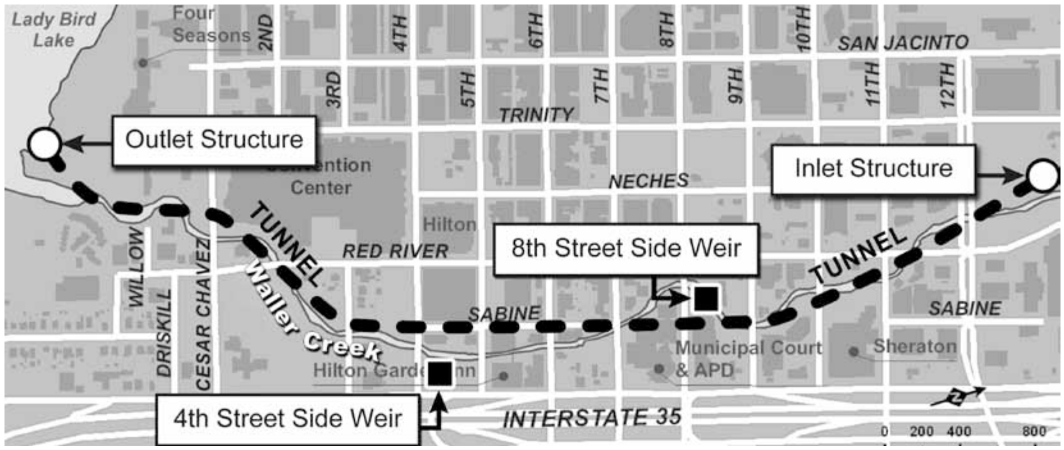

FIGURE 1 Waller Creek Tunnel Project Map

The primary design elements, or sub projects, of the Waller Creek Tunnel Project include: 1) inlet at Waterloo Park, 2) outlet at Waller Beach, 3) main tunnel, and 4) creek side tunnel inlets. These elements are described below.

- The inlet includes the construction of an approach channel and pond, morning glory spillway to convey floodwaters of Waller Creek, the inlet shaft, a short tunnel segment (stub) that includes a debris pocket, mechanized screening facilities, recirculation pump system, and pump house facility. The inlet also includes an in-line dam to divert Waller Creek into the tunnel.
- The outlet includes the construction of the outlet lagoon and spillway that conveys diverted floodwaters into Lady Bird Lake, the outlet shaft, a short tunnel segment (stub), and associated park trails.
- The tunnel element includes the main line tunnel, approximately one mile in length, to convey floodwaters from Waterloo Park to Lady Bird Lake. The tunnel extends through varied geologic formations that include shale, limestone, and two fault zones. The tunnel also includes lateral connections that connect the creek side tunnel inlets.
- The creek side tunnel inlets at 4th and 8th Street (see Figure 1 Waller Creek Tunnel Project Map and Figure 2 Schematic Profile) convey additional flood flows into the tunnel from the intervening drainage area downstream of 12th Street. The two creek side tunnel inlets include screening facilities, check dams to divert creek flow into the inlets, and associated creek bank stabilization and restoration.

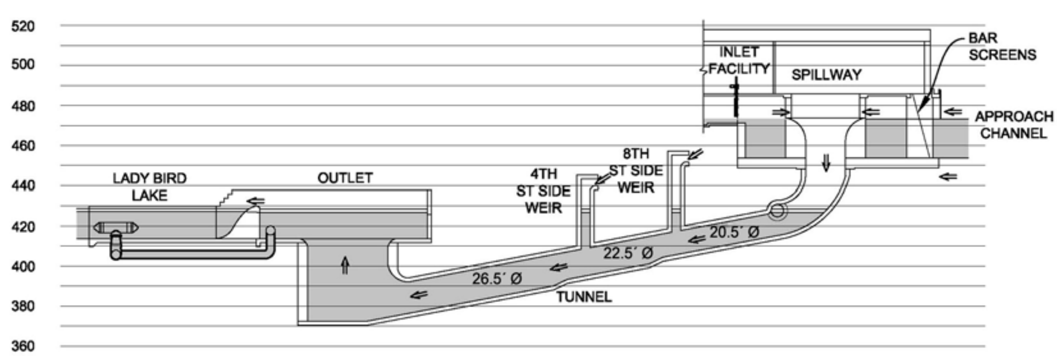

FIGURE 2 Schematic Profile

FACILITY PURPOSE

The tunnel outlet structure directs the floodwater out of the flood control tunnel and into the waters of Lady Bird Lake. The geometry of the interior of the outlet structure is configured to minimize hydraulic energy losses, providing a gradual hydraulic transition of the discharged floodwater from the tunnel outlet shaft into Lady Bird Lake. The tunnel outlet structure has maintenance access facilities and a recirculation intake screen system as an integral part of the facility. Architectural treatment and landscaping of the outlet structure and the surrounding site are part of the integration of the facilities into the Waller Creek and Lady Bird Lake setting (see Figure 3 Outlet Facilities Rendering).

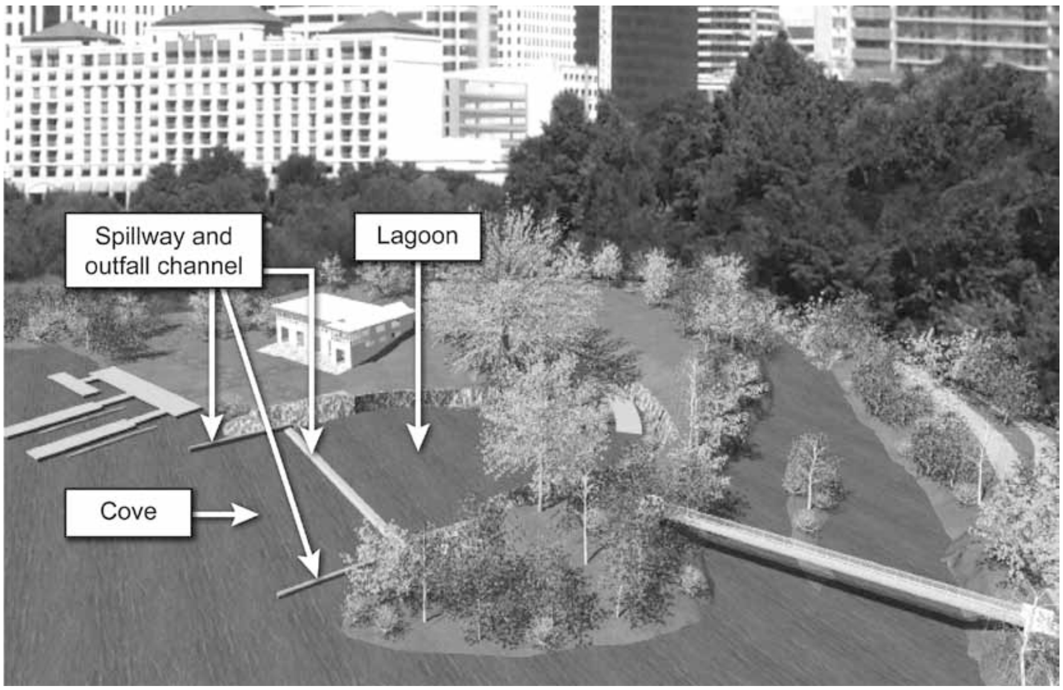

FIGURE 3 Outlet Facilities Rendering

Recirculation System

The purpose of the tunnel recirculation system is to prevent the water in the tunnel from becoming septic during dry weather conditions. Tunnel recirculation has an additional benefit of providing a base flow to Waller Creek during dry weather and improving the water quality. The recirculation of the tunnel water is controlled at the inlet by the recirculation pumps. The outlet facilities contain the water intake facility for the recirculation system.

Dewatering

Periodic cleaning and maintenance of the tunnel requires dewatering. In order to minimize the risk of a septic condition developing in the stagnant tunnel water, the entire tunnel should be dewatered within 48 hours. While the number and capacity of pumps that are being run at any one time may vary, an average flow rate of approximately 20 cfs would be necessary to accomplish this dewatering requirement. When dewatering and cleaning is complete, the tunnel and outlet structure fills using the butterfly valve in the recirculation line to control the flow. It takes a 3- to 4-day period for this manual operation to be completed.

Design Flood Flow

The design flow out of the flood control tunnel into the outlet structure is 8,661 cfs during a 100-year flood with the diverted lower Waller Creek lagging stormwater inflows from creek side tunnel inlets at 4th and 8th Street. The average velocity of stormwater in the tunnel would be approximately 20 fps. The purpose of the outlet structure is to dissipate this high energy and velocity from the tunnel to minimize erosion to the shoreline of Lady Bird Lake.

OUTLET FACILITY FEATURES

The vertical outlet shaft is the means by which the stormwater flow velocity is decreased and the majority of the energy from the tunnel flow is dissipated. In order to channel the stormwater in an evenly distributed manner from the circular vertical shaft to the long horizontal weir, a semi-circular approach channel (cove) is used to collect the water and direct it toward Lady Bird Lake. A 150-ft long Ogee weir controls flow from the outlet structure into Lady Bird Lake. The outlet weir is 16 ft high for structural integrity and has a weir crest set 2 ft above the average Lady Bird Lake water surface level of elevation 428 ft. The weir serves as a means to keep Lady Bird Lake water from entering the cove and tunnel during dewatering and debris removal. The discharge (exit) channel comprises a concrete bottom and vertical training walls that fully contain the poorly formed hydraulic jump of the flood flows as they are discharged into Lady Bird Lake.

Tunnel Transition

In order to reduce the stormwater velocity in the tunnel from 15 fps to the desired exit velocity of approximately 6 fps, the inside diameter of the vertical shaft is computed to be 40 ft. Head losses resulting from transition of the high velocity flow in the 26.5-ft diameter equivalent tunnel into the vertical, 40-ft diameter tunnel shaft are significant (approximately 2.4 ft of head). Analysis of this transition in the hydraulic physical model demonstrated that the physical configuration dissipates the hydraulic momentum in a controlled, predictable regime.

Outlet Lagoon (Weir Approach Channel)

In order to channel the stormwater in an evenly distributed manner from the circular vertical shaft to the long horizontal weir, a semi-circular approach channel was chosen to collect the water and direct it toward Lady Bird Lake. The distance from the shaft to the rear wall is 21 ft, which will assist energy dissipation by allowing free-flow out of the tunnel shaft in all directions, rather than directing it all immediately to the lake. The diameter of the wall curve is determined by the width of the structure (150 ft). The distance from the shaft to the weir is the same distance as the shaft to the side curved walls. This allows the stormwater to evenly distribute along the weir as demonstrated in the physical hydraulic model. The elevation of the outlet lagoon was lowered from 418 ft to 414 ft in order to excavate alluvium, a thin limestone and a thin bentonite layer. This allows the lagoon bottom concrete slab to be poured on sound limestone, thereby avoiding expensive sub-grade stabilization. The increased depth of approach to the spillway improves its hydraulic performance by reducing head losses.

Weir (Ogee Spillway)

The weir serves two purposes: it controls the velocities into Lady Bird Lake to minimize scouring of the lake bottom and it holds back the lake water when the tunnel must be de-watered and cleaned. A 150-ft long Ogee weir controls flow from the outlet structure into Lady Bird Lake. The outlet weir is 16 ft high for structural integrity and has a weir crest set 2 ft above the average Lady Bird Lake water surface level of elevation 428 ft, which is closely maintained at this constant level. The weir crest height, at elevation 430 ft, is set high enough to prevent Lady Bird Lake water from entering the structure during dewatering.

The purpose of the weir is to allow for dewatering and maintenance without the expensive construction of a coffer dam each time dewatering takes place. The weir's Ogee spillway safely and efficiently discharges the 100-year storm event, or 8,661 cfs, into Lady Bird Lake while limiting a 100-year water surface elevation to

436.06 in the outlet cove thereby minimizing the hydraulic backwater effects on the flood control tunnel. The spillway passes the 100-year event with 6.1 ft of head.

The Ogee weir supports the nappe until the intersection of the spillway with Lady Bird Lake water surface. The nappe intercepts the tailwater from Lady Bird Lake where a boil resulting from a poorly formed hydraulic jump occurs. The boil becomes progressively higher with larger discharges until it floods out, showing only a slight depression and eddy at the surface.

Outlet Cove Discharge (Exit) Channel

Lady Bird Lake is a fairly shallow, constant level lake with a normal pool water surface elevation of approximately 428 ft. The 100-year flood level for Lady Bird Lake is at elevation 441.4 ft. The width (150 ft) and depth (14 ft) of the channel is set to prevent scouring by keeping the stormwater that is exiting the outlet structure at velocities of approximately 4 fps at the design flow of 8,661 cfs. For storms that produce flows in excess of that event, diver inspection for possible scour would be needed. The exit channel comprises a concrete bottom and vertical training walls that fully contain the poorly formed hydraulic jump of the discharged flood flows. Beyond the concrete apron that contains the jump, an open cut in the lake bottom extends the exit channel at elevation 414.0 ft into the lake.

GEOTECHNICAL, EXCAVATION AND STRUCTURAL CONSIDERATIONS[1]

There are several construction challenges to the outlet structure including the presence of groundwater, subgrade soils, consisting of cohesionless "running" alluvial soils, and proximity to Waller Creek and Lady Bird Lake. Figure 4 Outlet Structure Boring Location Plan shows the location of the numerous borings taken to develop a geologic understanding of the site. Figures 5 Outlet Structure Subsurface Profile A and Figure 6 Outlet Structure Subsurface Profile B illustrate the complex geologic stratigraphy of the site.

Excavation Potential

Excavation through the alluvium and overburden soils should proceed without significant difficulty. Advancement into the limestone and shale strata will present more challenges (see Table 1).

Trench and confined excavations into the Austin Limestone and the upper members of the Eagle Ford will require heavy-duty excavators, rock saws, pneumatic rams, or other similar equipment. In addition, vibrations induced by excavation into the limestone and shale will need to be considered in nearby excavation bracing stability.

TABLE 1 Summary of REC, RQD, and Compressive Strength of Rock Core Samples

Formation	REC	RQD	UC
Austin Limestone	70 to 100 (average 98)	0 to 100 (average 86)	347 to 4083 (average 2013) psi
Eagle Ford Shale	80 to 100 (average 99)	16 to 100 (average 83)	35 to 1694 (average 669) psi

REC – Rock Core Recovery, % RQD – Rock Quality Designation, %
UC – Compressive Strength

Temporary Slopes

Temporary excavations will be necessary for construction of below grade structures, foundations, and underground utilities. These excavations can be open-cut, provided there is sufficient room to slope the excavation sides and considerations are made for structures bearing in backfill soils. Appropriate measures will be needed to maintain the stability of excavation sidewalls. These required measures would depend on the depth and width of the excavation.

Suggestions in accordance with OSHA[2] for classifying soil and rock encountered in the investigation are outlined in Table 2.

TABLE 2 OSHA[2] for Classifying Soil and Rock

Formation	OHSA Classification	Recommended OSHA Slope
Overburden soils consisting of low plasticity fill, alluvium, and completely weathered limestone	Type B	1H to 1V*
Weathered or jointed Limestone, Eagle Ford Shale	Type A	¾H to 1V
Competent limestone	Stable Rock	Vertical sides**

* If groundwater is encountered within the lower elevations of the stratum, flatter slopes of at least 1.5H to 1V or flatter will be required to maintain excavation safety. This flatter slope will control the sloping of the excavation and should be continued to the ground surface.
** If faulting, jointing, and/or inclined discontinuities are exposed, flatter slopes will be required to maintain safe trench excavations. Assume Type A (¾H to 1V).

Braced Excavations

In excavations where side slopes cannot be maintained due to lateral constraints, excavation support systems will be needed. The design of temporary excavation support systems is the responsibility of the contractor's licensed engineer in conformance with OSHA requirements. Typical temporary retention systems could consist of drilled shaft soldier beams and wood lagging. With the depths of cuts required, a tied-back system will likely be necessary. Due to the proximity of the outlet structure to Waller Creek, the tie-backs will need to be anchored in the Austin Limestone beneath Waller Creek. According to boring BO-312, the Austin Limestone was encountered at elevation 419.6 ft. Provided contour information indicates a creek bed elevation of 420 ft to 425 ft in Waller Creek. Accordingly, tiebacks would need to extend at least 5 ft into the Austin Limestone below elevation 420 ft before tie-back grout tensioning can be accrued. Tie-backs embedded in the Austin Limestone may be designed using a pull-out resistance of 500 psf for the portion of the grouted anchor extending outside and likely below the "active" zone. Tie-backs should be installed and tested in general accordance with the 2006 Post-Tensioning Manual, Sixth Edition. Testing should include a limited number of preproduction tests, and both performance tests and proof tests during production. Alternatively, more innovative vertical bracing systems are available including vertical walls such as drilled shaft walls with vertical tie-back or "tie-down" tensioned anchors.

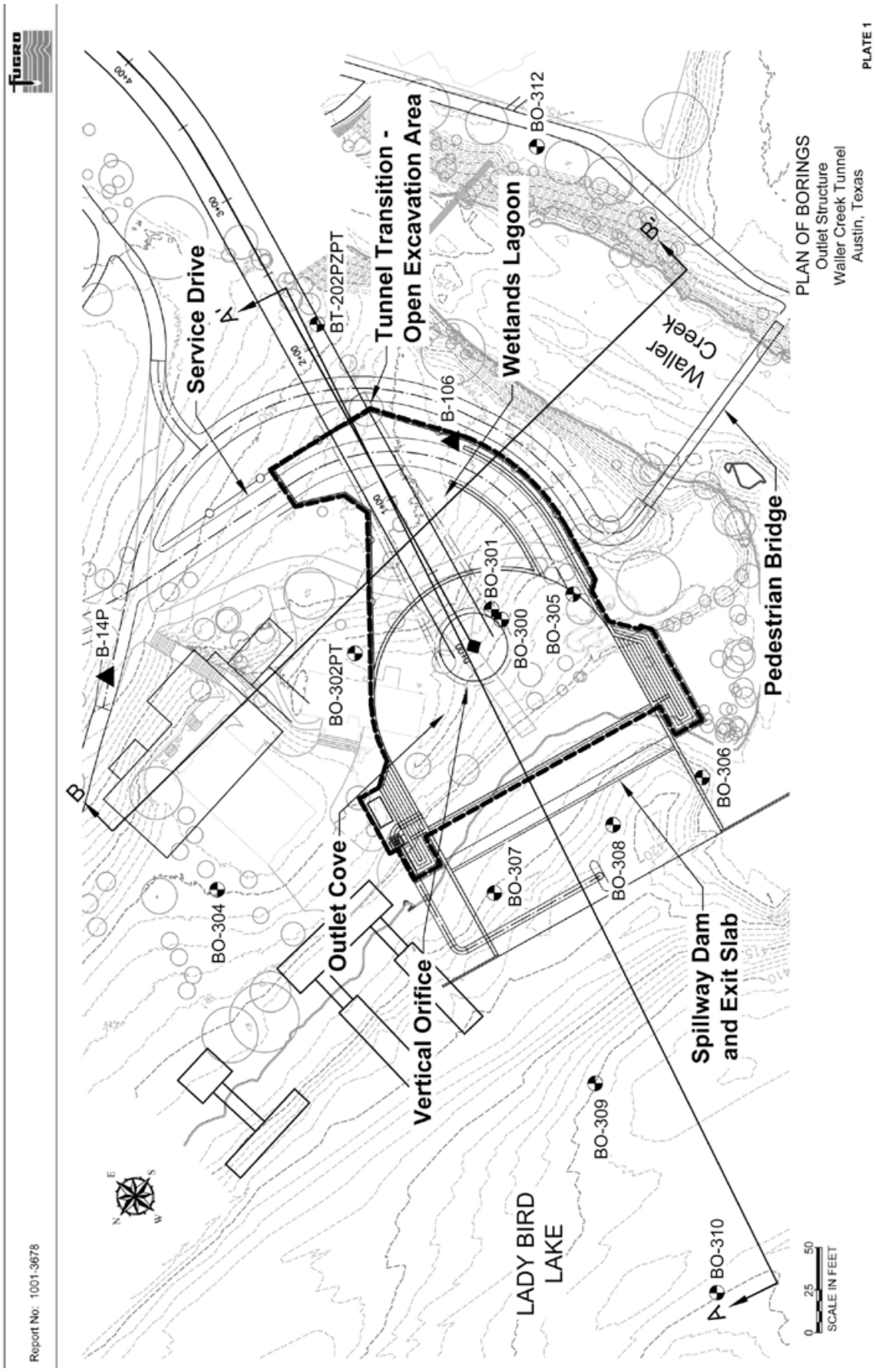

FIGURE 4 Outlet Structure Boring Location Plan

Intake Pipe

The intake pipe will be constructed beneath the discharge apron with a horizontal pipe invert of 404 ft. The excavation for the 54-in pipe will likely encounter Austin Limestone and require the use of heavy-duty excavation equipment such as a rock saw or large track-mounted backhoe equipped with a pneumatic hammer. The pipe will be backfilled with lean concrete (minimum compressive strength of 500 psi). Provisions will be made during construction to secure the pipe during lean concrete placement and curing so that the pipe does not float or lose position.

Groundwater and Dewatering

A rigorous and well-designed dewatering plan will be essential for proper installation of the outlet structure and associated foundations. A "floating dike" system is planned to serve as a coffer dam and impound Lady Bird Lake. Based on planned foundation construction elevations of approximately 412 ft (top of concrete elevation 414 and assumed slab thickness of 2 ft), locally lower (i.e. turn-down footing for Exit Slab), and a normal pool elevation of 428 ft for the lake, 16 ft or more of water will need to be impounded.

In addition to surface water impoundment, generally 5 to 25 ft or more of saturated, cohesionless alluvium will require seepage cutoff (particularly beneath the cofferdam impounding the lake), dewatering, and stabilization (by means of retention systems or sloping). It is likely that the lower portions of the alluvium, consisting of high permeability sands, gravels, and cobbles, are in direct communication with the lake and will introduce significant quantities of groundwater into excavations. It is common to require dewatering contractors to achieve and maintain a lowered groundwater elevation of at least 3 ft below the lowest planned excavation subgrade elevation.

A groundwater head of 16 ft or more in fractures and/or weathered planes in the bedrock strata may be problematic. The presence of groundwater in fractured parent rock, the upper surface of the Austin Limestone, and/or the interface between the Austin and underlying Eagle Ford may need to be addressed with pressure grouting of the parent rock formation prior to excavation.

Piezometer and packer test data may be insufficient to fully assess groundwater infiltration potential and rates for this planned excavation. Additional field testing, such as a pump test or possibly a slug test, may be required to assess field permeability rates in the alluvium and corresponding groundwater transmissivity potential.

Based on previous experience and site specific field permeability data presented (packer tests), the following presumptive field permeability values were developed (See Table 3) for cost estimating purposes by the design team. These values are for planning purposes only, and the contractor should develop his own values for design and construction of the dewatering plan.

TABLE 3. Presumptive Permeability Values

Soil Type	Suggested Permeability
Alluvium –(clayey, silty sand)	1 x 10-3 cm/s
Alluvium – (gravel)	1 x 10-2 cm/s
Austin Limestone	1 x 10-5 cm/s
Eagle Ford Shale	1 x 10-4 cm/s
Buda Limestone	1 x 10-8 cm/s

A dewatering contractor will perform surface water and dewatering control. The system designed will likely consist of a coffer dam to impound Lady Bird Lake, a seepage cutoff system to allow excavation in the alluvium stratum, and a system of well points or deep wells providing dewatering of the alluvial soils across the outlet structure site. A groundwater control plan and seepage cutoff will likely be required along Waller Creek in addition to the lake. The contractor should maintain the groundwater level at least 3 ft below the planned excavation depth.

Control of not only surface water, but also groundwater will be essential in proper construction of the outlet structure and tunnel transition. If groundwater is not properly controlled, foundations and excavation stability will be compromised.

CONCLUSION

The Waller Creek Stormwater Tunnel Program is a City of Austin flood control and redevelopment project located along the east side of downtown Austin, Texas. The project is designed to divert 100-year flood flows from Waller Creek just upstream of 12th Street into a ±5,700-lf long flood control tunnel that discharges into Lady Bird Lake. This paper outlined the complex geotechnical and environmental constraints that dictated specific engineering rationale, design features, and construction methodology for the Waller Creek Tunnel Outlet Facilities at Waller Beach. The project, scheduled to be completed in 2014, will provide flood control and redevelopment for the community for many years to come.

REFERENCES

[1.] Final Geotechnical Design Memorandum Outlet Structure, Waller Creek Tunnel, Austin, Texas, Fugro Consultants, Inc.

[2] Code of Federal Regulations Title 29 Part 1926 (2003), “Labor”, Occupational Safety and Health Administration, Department of Labor, Subpart P - Excavations, pgs 373 – 410.

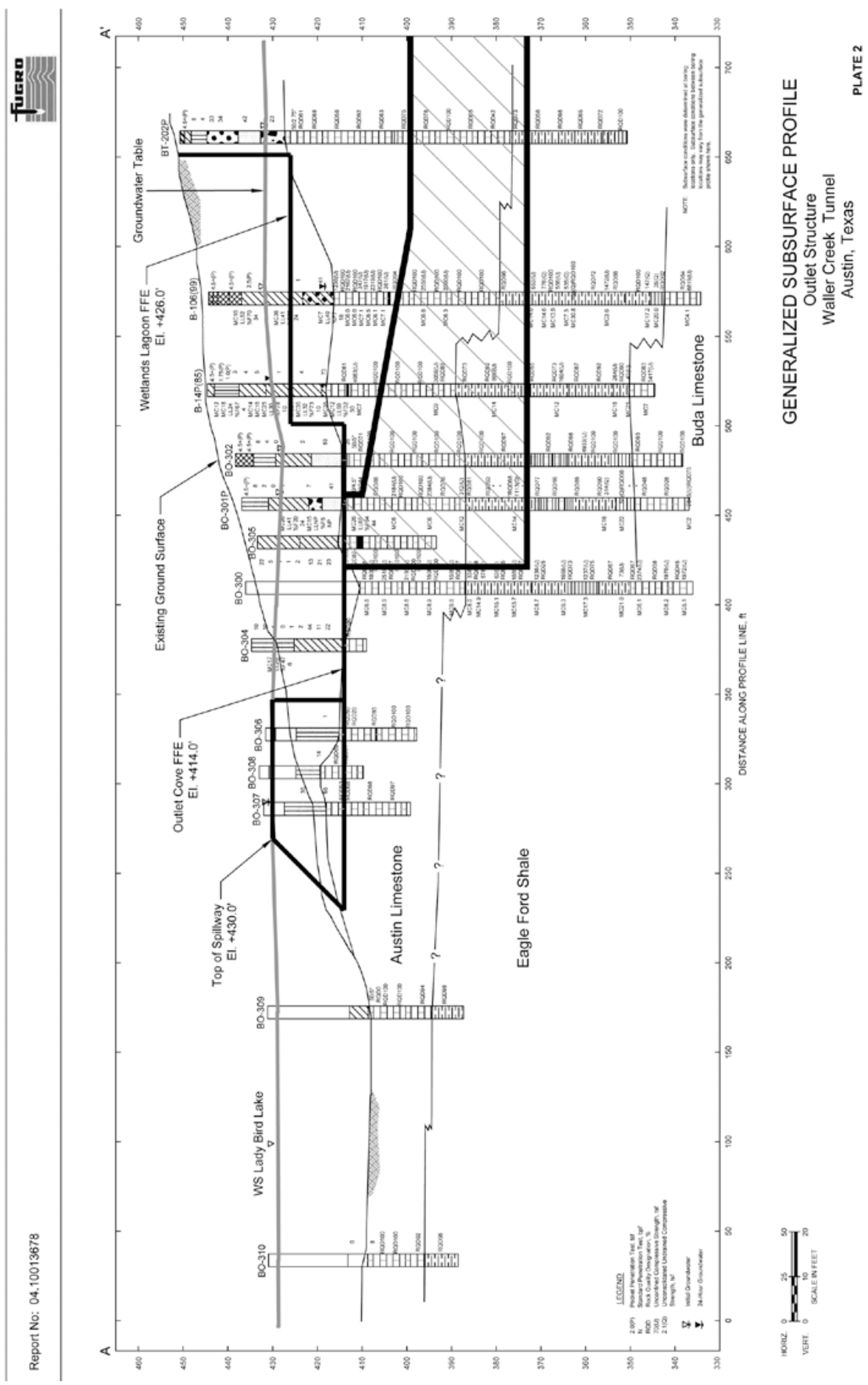

FIGURE 5 Outlet Structure Subsurface Profile A

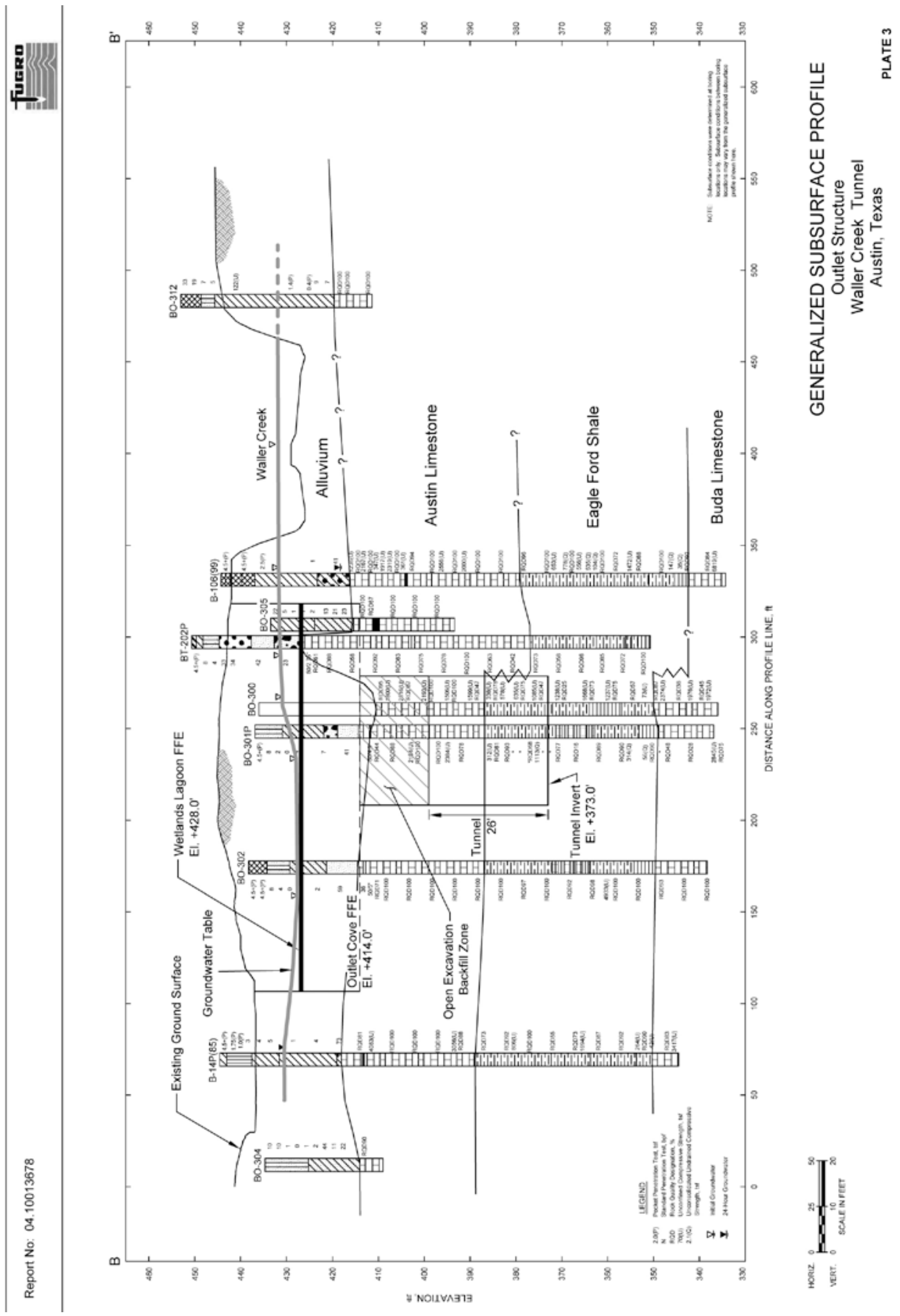

FIGURE 6 Outlet Structure Subsurface Profile B